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Millicompost: Sustainable substrate for the production of dragon fruit seedlings (*Selenicereus undatus*)

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A R T I C L E I N F O

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A B S T R A C T

The success of the production of dragon fruit seedlings propagated vegetatively depends on several factors, such as the appropriate choice of the substrate for rooting. It has been verified that the millicompost has contributed to the production of seedlings of some species, however, there are no reports for the dragon fruit. Thus, the objective was to evaluate the efficiency of the millicompost generated by the activity of the diplopods *Trigoniulus corallinus* in the cuttings of the red dragon fruit. The substrates used were: S1) millicompost, S2) sand + bovine manure and S3) Biomix®. Characterizations of the physical-chemical, chemical, and physical properties of the substrates were carried out. The phytotechnical parameters evaluated in the cuttings of dragon fruit were: number of shoots, length of the largest shoot, fresh and dry masses of the shoot and roots. The millicompost had physicochemical, chemical, and physical properties, promoting greater development of dragon fruit, whose levels of nutrients and physical characteristics, in addition to being superior to the other substrates, were able to provide seedlings of higher quality and size compared to seedlings from the other two substrates tested. The millicompost represents an alternative as an organic substrate in the vegetative propagation of the dragon fruit tree by providing increments of the vegetative characters and biomass production, confirmed by the greater inputs of nutrients accumulated in its plant tissue.

1. Introduction

The dragon fruit tree (*Selenicereus* spp) is a promising fruit because its fruits have nutraceutical properties, besides it is a species of easy handling and adapted to the conditions of low water availability during its cycle, arousing the commercial interest of its seedlings and fruits. This fruit has its origins in the Americas, occurring even in Brazilian territory. It has a succulent, photosynthetically active stem, known as cladodium, fasciculated roots, epiphytic habit, large bell-shaped flowers, large fleshy fruits, with numerous seeds. For its cultivation it needs to be tutored with supports of 1.5–2 m, it responds well to fertilization and irrigation. It needs artificial shading and can reach fruit production of 15–30 tons per hectare year^{-1}. It has great potential to be used as an ornamental, in addition to being a source of high demand composts in national and international markets (Donadio, 2009), (Mizrahi, 2014), (Nunes et al., 2014) and (Moreira et al., 2020). Although the harvest occurs when the fruits are fully ripe, there is no consensus on the classification of their behavior as climacteric or not (Nunes et al., 2014).

The propagation of the dragon fruit tree is usually done through cutting, because the use of seeds presents many disadvantages for commercial production, since plants originating from seeds have a long youthful period (Gonçalves et al., 2020) and, still, to constitute genotypes with an inferior quality of the parent plant.

Dragon fruit tree propagated by cuttings starts flowering in the first or second year of cultivation. Thus, in addition to the fastest production, a plantation formed by the use of cuttings has greater uniformity, a characteristic very desired for this crop (Almeida et al., 2016). Asexual propagation requires studies on which practices, management, and inputs can induce the greatest initial growth of roots and sprouts. Among

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the determining factors, the substrate of recognized quality is essential to provide the cuttings with vigorous and uniform growth so that later there is the transplantation of vigorous seedlings to the field of cultivation.

There are numerous commercial substrates on the market, but, unfortunately, many do not have proven quality. Bearing in mind that a limiting factor for seedling production is the acquisition of quality substrates at costs that make the business feasible, it is important to constantly develop technologies that enable the development of substrates from low-cost materials and easy acquisition (Bugni et al., 2019), in addition to contributing to cost reduction and ensuring obtaining seedlings with an adequate standard. However, the composition of the substrate is one of the factors of the greatest influence on the rooting of cuttings. This should provide moisture, make macros and micronutrients available; in addition to enabling the necessary: aerated, dark environment, and promoting plant sustainability.

The physical, physical-chemical, chemical, and biological properties of the substrates reflect their quality and the success of their use. For this reason, characterizing its properties becomes essential and helps to better understand the plant development of the species.

Among the sustainable practices in the production of seedlings, organic composts, in general, have biological properties suitable for their use as substrates for seedlings, as they are capable of providing the nutrients necessary for the growth of various crops. In this sense, the use of organic waste as suppliers of nutrients and support to compose substrates may represent an alternative to reduce the cost of seedling production in general for the producer (Antunes et al., 2018).

The vermicompost (obtained by the action of earthworms) is the best known and studied in the world. However, in recent years the millicompost has gained notoriety for its peculiar characteristics, such as, for example, not needing to combine more raw materials to improve its physical, physical-chemical, and chemical properties, is readily used as a substrate afterward millicomposting process completed (Antunes et al., 2018).

Several diplopods (popularly known as millipedes) can be used in millicomposting because of their ability to crush various types of coarse organic waste. In Brazil, studies with the species *Trigoniulus corallinus* have shown that millicompost obtained from agricultural residues has physicochemical characteristics similar to vermicompost (Antunes et al., 2016) and recently it was proved its efficiency in the production of lettuce seedlings, which destined for the production beds, presented an excellent agronomic performance, which was due to the excellent quality of the seedlings produced in it (Antunes et al., 2018).

However, technical information in the literature regarding the use of millicompost as a substrate in the propagation of the species through cuttings is scarce. Based on the above, it is assumed that the millicompost is capable of making a positive contribution to the production of dragon fruit tree seedlings. Thus, the objective was to evaluate the efficiency of the millicompost generated by the activity of the diplopods *Trigoniulus corallinus* in the propagation of cuttings of the red dragon fruit with white pulp.

2. Material and methods

The experiment was implemented on October 15, 2015, and conducted in a greenhouse in the Crop Science Department, of the Agronomy Institute of the Federal Rural University of Rio de Janeiro, located in the municipality of Seropédica-RJ. The location's altitude is 33.0 m and the region's climate is Aw, according to the Köppen classification, with concentrated rain between November and March, the average annual temperature of 23.9 °C, and average annual precipitation of 1213 mm (Oliveira Júnior et al., 2014).

For the production of the millicompost necessary in the experiment, the following components and their respective percentages in the mixture were used: branches and leaves of *Gliricidia sepium* (Jacq.) Walp. at 20%, branches and leaves of *Leucaena leucocephala* (Lam.) of Wit at 20%, grass clippings *Brachiaria decumbens* Stapf. at 30%, branches and leaves of *Mimosa caesalpiniaefolia* at 20% and cardboard chopped into pieces (≤4 cm) at 10%. Material preparation and consumption by *Trigoniulus corallinus* diplopods were carried out according to Antunes et al. (2016). After six months, the material was sieved in a 2 mm mesh, the fine material used in the experiment as a substrate. As the outermost part of the waste used in millicomposting loses more moisture, these usually persists and is not processed by the millipedes. For this reason, the millicompost needs sieving to be used standardized way (Fig. 1). The coarse material is returned to the containers to be composted with new mixtures of plant residues.

The cladodes of the red dragon fruit of white pulp (*Selenicereus undatus*) were obtained in Fazendinha Agroecológica-Km 47, in Seropédica-RJ. The cuttings were standardized at 20 cm in length and planted in plastic pots (height 17 cm, diameter 21 cm, and capacity for 5 L) filled with the three different substrates: S1-Millicompost, S2 - 50% sand, and bovine manure 50% (v/v) and S3 - Biomix® commercial substrate. A completely randomized design with five replications per treatment was used. Each replicate (pot) consisted of five dragon fruit tree cuttings, totaling 25 cuttings per treatment.

The determination of the N, P, K, Ca, and Mg contents of the evaluated substrates were carried out according to the methodology used by Teixeira et al. (2017). To quantify the organic matter and total carbon content (C_{total}) present in the substrates, the gravimetric method was used, which consists of burning the material in muffle at 550 °C for 4 h (Goldin, 1987). The factor of 1.8 was used to convert organic matter into C_{total}, as suggested by Jiménez and García (1992). The pH analyzes were carried out in a distilled water solution (5: 1 v/v) and the electrical conductivity was determined in the same aqueous extract obtained for the pH measurement according to the method described by Brasil (2008). Physical analyzes to determine volumetric density and particle density, macroporosity, microporosity, total porosity, and water retention capacity, were performed using the methodology described by Teixeira et al. (2017).

At 90 days after planting, the following parameters were evaluated per cut: number of shoots, length of shoots, fresh and dry masses of the of the shoot and roots. To determine the dry masses of shoot and roots, the different organs were placed in an oven at 65 °C, maintained for 72 h until a constant weight was obtained.

The contents of total macronutrients (N, P, K Ca and Mg) contained in the aerial part of the plants collected at 90 days after planting in the pots, obtained from the grinding of the dry masses of the plants in a Willey knife mill were determined (Teixeira et al., 2017). To establish the quantities of each nutrient accumulated per plant, the value of the contents of each nutrient (g kg^{-1}) was multiplied by the dry mass of the aerial part of the plant, obtaining the data of macronutrient accumulation in mg $plant^{-1}$.

For data analysis, an evaluation was made of the homogeneity of error variances using the Bartlett test and normality using the Shapiro-Wilk test. The data were submitted to analysis of variance with the application of the Tukey test ($p < 0.05$) using the SISVAR statistical program (Ferreira, 2014).

3. Results and discussion

3.1. Physical-chemical and chemical properties of substrates

Table 1 shows that the substrates had the following pH values at the time of the experiment: 6.08 for the millicompost, 7.20 for the substrate consisting of sand + manure and 6.74 for the commercial substrate Biomix®; and electrical conductivities (CE), expressed in deci Siemens per meter (dS m^{-1}), respectively: 2.65, 0.88 and 0.46.

Carrying out a thorough review of the theme, it appears that few studies report the chemical characterization of substrates processed by diplopods. Apurva et al. (2014) worked with a substrate processed by *Harpaphe adenine* (Wood) and obtained a pH of 7.20 and an EC of 0.24

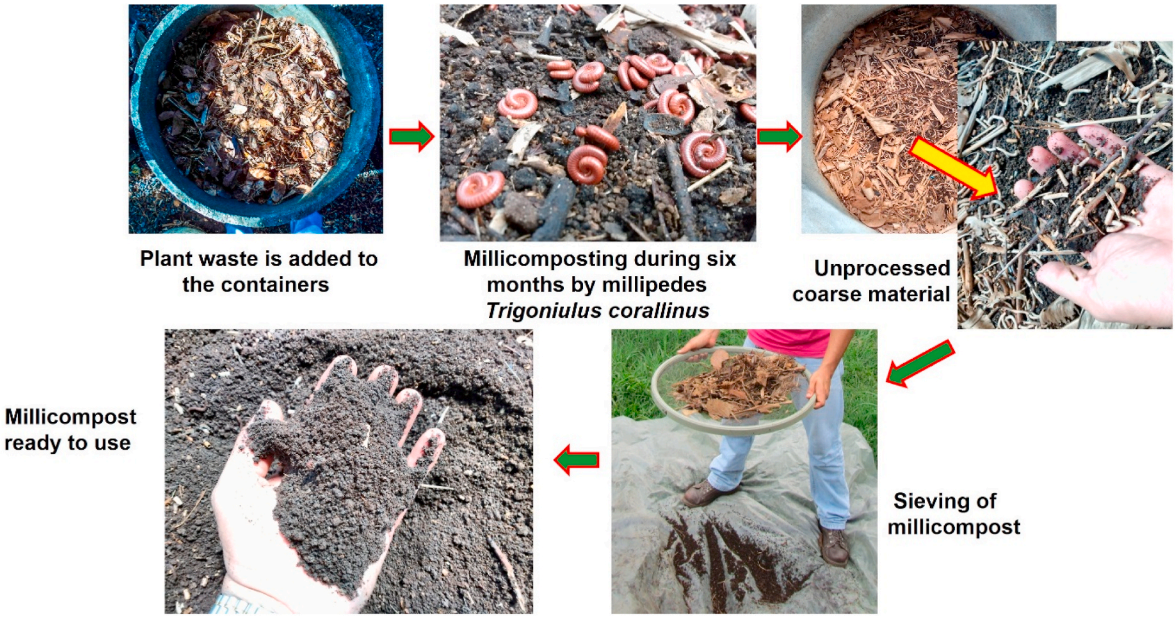

Fig. 1. Sequential scheme of the millicomposting process by diplopods *Trigoniulus corallinus* and sieving of compost for use a substrate.

Table 1
pH values, electrical conductivity (EC), contents of total macronutrients, organic matter and C/N ratio of the substrates used for the production of red dragon fruit tree white pulp seedlings propagated by cuttings and their respective coefficients of variation (CV).

Parameter	Unity	Substrates		
		S1 - Millicompost	S2 - Sand + Manure	S3 - Biomix®
pH (CV = 3.15)	–	6.08 b	7.20 a	6.74 b
CE (CV = 4.10)	dS m^{-1}	2.65 a	0.88 b	0.46 c
C_{total} (CV = 3.46)	g kg^{-1}	372.2 a	44.4 c	273.3 b
N_{total} (CV = 3.10)	g kg^{-1}	29.0 a	1.40 c	6.10 b
P_{total} (CV = 2.34)	g kg^{-1}	3.47 a	0.43 c	2.63 b
K_{total} (CV = 4.30)	g kg^{-1}	11.65 a	1.84 b	2.55 b
Ca_{total} (CV = 5.22)	g kg^{-1}	21.52 a	0.94 b	22.26 a
Mg_{total} (CV = 4.80)	g kg^{-1}	5.71 a	1.12 c	2.34 b
Organic matter (CV = 3.10)	%	74.44 a	8.88 c	54.66 b
C/N ratio (CV = 3.93)	–	12.83 c	31.71 b	44.80 a

Same letters on the line do not differ from each other, by the Tukey test ($p < 0.05$).

dS m^{-1}. These differences pH values and electrical conductivities are related to the material of plant origin used in the millicomposting process since they exhibit varying levels of nutrients, which may result in an organic compost more or less rich in nutrients (Antunes et al., 2019a). The pH value influences the solubility and availability of nutrients for plants. Kratz and Wendling (2013) report that when it comes to the use of organic substrates, without the addition of soil in the composition, the recommendation is to work in a pH range of 4.4–6.2. With the exception of millicompost (S1), the other substrates showed pH values above the recommended by the authors, ranging from 6.74 to 7.20 (Table 1).

In general, electrical conductivity (EC) indicates how the levels of concentration of salts contained in the substrates are. According to Minami and Salvador (2010), EC values above 3.4 dS m^{-1} are considered too high for substrates, values from 2.25 to 3.39 dS m^{-1} are high, values from 1.8 to 2.24 dS m^{-1} are slightly high, values from 0.5 to 1.79 dS m^{-1} are moderate, values between 0.15 and 0.49 dS m^{-1} are low and values below 0.14 dS m^{-1} are considered very low. Thus, the substrates S1, S2, and S3 presented CE considered high, moderate, and low, respectively (Table 1).

The average values of the total nutrients and organic matter of the evaluated substrates were higher for the substrate S1 - millicompost, when compared to the other substrates, and the average values of total calcium was similar to that observed in the substrate S3- Biomix®. Apurva et al. (2014) observed such nutritional superiority of the compost processed by diplopod (*H. haydeniana*) compared to the other treatments, which consisted of soil, vermicompost, and soil + manure. Antunes et al. (2016) concluded that the decomposition of vegetable and urban residues made with the use of *Trigoniulus corallinus* enriches the substrate with calcium, magnesium, and phosphorus, a result that confirms the data observed in this work. ASHWINI and SRIDHAR (2006) also demonstrated an increase in the concentration of N, P, K, Ca, and Mg in the compost produced with the help of diplopods and earthworms.

The higher values of N, organic matter, and P are related to the chemical characteristics of each plant material used in millicomposting, in which this combination of residues in different proportions contributed to the better processing by the diplopods and, consequently, in obtaining a compost with balanced levels of nutrients (Antunes et al., 2018). Ramanathan and Alagesan (2012) observed that, in addition to the excreta of diplopods, the microorganisms present in their feces promote significant increases in the nitrogen content contained in the substrate, potentiating the growth of plants in relation to other substrates, such as vermicompost and compost from compost.

Another important parameter in the characterization of the substrates is the C/N ratio, which signals how the organic materials are at the end of the composting process (Da Ros et al., 2015). Normative instruction number 25 of the Ministry of Agriculture, Livestock and Supply - MAPA (Brasil, 2009) highlights that the C/N ratio cannot exceed 20 and the total nitrogen content must be at least 5.0 g kg^{-1} for organic composts. The substrate S3 showed a C/N ratio of 44, considered high to the adequate mineralization of nutrients, and there may be, at first, the immobilization of mineralized N (Antunes et al., 2019b). However, this result occurs at the expense of the components of its formulation, such as pine bark, which has a high C/N ratio, influencing the final value of this relationship. The millicompost showed a C/N ratio of 12.83, showing the stabilization and ability to provide the necessary nutrients to the plants, meeting the standards mentioned.

3.2. Physical properties of the substrates

The volumetric density and particle density recorded for the millicompost were 180 kg m^{-3} and 1440 kg m^{-3}, respectively (Table 2). In the substrate constituted by the mixture of sand and manure the densities were 1070 and 2470 kg m^{-3} and in the commercial substrate Biomix® of 310 and 1790 kg m^{-3}. The percentages of total porosity and microporosity were higher in the millicompost than in the other substrates, a result that contributed to the greater water retention capacity in the millicompost (Table 2). The size and structure of the fecal pellets of the millipeds, whose particles are spherical and measure about 1.85 mm, were responsible for maintaining high porosity of this substrate, unlike other composted materials, which are highly compacted and reduce the porosity of the media cultivation (Pascual et al., 2018).

Results similar to this work were observed by Apurva et al. (2014), who considered that the highest percentage of organic matter is responsible for volumetric density, inorganic components for particle density, porosity, and water holding capacity are dependent on the interaction between organic and inorganic components present in the substrates. Ramanathan and Alagesan (2012) also observed that the physical properties of the compost processed by diplopods were able to promote greater aeration and water retention for maintaining moisture and plant development of *Capsicum annuum* in pots. Fermino (2003) considered as a reference for substrates values of volumetric density between 100 and 300 kg m^{-3}, values observed in this work for the substrates S1 (millicompost) and S3. The substrate S2, because it contains sand - dense mineral material, did not fit within the established references.

Values indicated as adequate for the total porosity are in the range of 75–85% (Gonçalves, Poggiani 1996) and, in this sense, only the substrate S2 - sand + manure, was not adequate, being 18.43% below the ideal range. Total porosity, as well as volumetric density, directly influences the water and nutrient absorption processes by plants (Kämpf 2001).

According to Gonçalves and Poggiani (1996), the adequate proportion of micropores (MIC) in substrates is between 45 and 55%, which was verified in the evaluated substrates, however, it should be noted that values slightly higher than this range were identified in the millicompost (Table 2), because it is a material with finer particles, resulting from the processing of residues used in millicomposting by diplopods.

As for macroporosity (MAC), Gonçalves and Poggiani (1996) consider the range of 35–45% to be the appropriate levels. The substrate S2 - sand + manure was the only one with low macroporosity (6.92%). The other substrates showed macroporosity ranging from 29.85 to 32.66% (Table 2), considered average levels by the aforementioned authors.

Table 2
Average values of volumetric density (DE volumetric), particle density (DE particle), percentages of total porosity (POT), microporosity (MIC), macroporosity (MAC) and water holding capacity (WHC 10) at 10 cm of column of water from the substrates used for the production of red dragon fruit white pulp seedlings propagated by cuttings and their respective variation coefficients (CV).

Parameter	Unity	Substrates		
		S1 - Millicompost	S2 - Sand + Manure	S3 - Biomix®
$DE_{volumetric}$ (CV = 0.21)	kg m^{-3}	180 c	1070 a	310 b
$DE_{partícle}$ (CV = 6.20)	kg m^{-3}	1440 c	2470 a	1790 b
POT (CV = 1.75)	%	87.42 a	56.57 c	82.50 b
MIC (CV = 1.64)	%	57.56 a	49.65 b	49.84 b
MAC (CV = 6.80)	%	29.85 a	6.92 b	32.66 a
WHC_{10} (CV = 1.64)	mL 50 cm^{-3}	28.76 a	24.83 b	24.92 b

Same letters on the line do not differ from each other, by the Tukey test ($p < 0.05$).

The water retention capacity is another important physical characteristic of any substrate for plants, because if it contains low retention capacity or retains excess water, it will not be suitable for the seedling production activity, since it will cause problems which will impact the vigor and quality of the seedlings, as a result, respectively, of the water deficit or excess water retention in the root environment. Adequate levels of water retention in plant substrates suggested by Gonçalves and Poggiani (1996) are between 20 and 30 mL 50 cm^{-3}. It can be noted that if all the substrates are within this ideal range, S1 - millicompost with greater water retention capacity (28.76 mL 50 cm^{-3}) and S2 and S3 substrates with similar WHC (Table 2).

3.3. Phytotechnical characteristics of dragon fruit tree propagated by cuttings

In general, all the characteristics evaluated were influenced by the substrates ($p < 0.05$) (Fig. 2), indicating that the substrate is an essential component in the production of seedlings of this species, and all the highest values observed occurred in those that were produced on the substrate S1 - millicompost (Fig. 2). Although millicompost is a substrate little used in agriculture, we verified in this experiment that its use contributed positively to the development of red dragon fruit tree seedlings propagated by cuttings, a fact confirmed by the great number and length of shoots that occurred in this substrate. Likewise, the fresh and dry masses of shoot part of the seedlings from the millicompost were higher than the masses registered in the substrates S2 and S3. Such differences represent, respectively, 61% and 21.45% more in the fresh mass and 25% and 15.92% more in the dry mass than the substrates S2 and S3 (Fig. 2).

The increase in vegetative characters and the higher production of fresh and dry biomass of seedlings are associated with the greater supply of nutrients contained in the millicompost (Table 1), as well as its physical properties (Table 2). In addition to the differences shown graphically in Fig. 2, in Fig. 3-A, there are clear differences between the millicompost seedlings in relation to the seedlings of the other substrates (Fig. 3B and C). Furlan et al. (2007), point out that the largest accumulations of the dry mass of shoots and roots during seedling formation are obtained on alternative substrates when these are compared to commercial substrates. Maggioni et al. (2014), highlight that substrates with lower densities, in addition to providing greater porosity, favor better drainage and less physical restriction on plant growth and development.

To maximize the production of seedlings, Galvão et al. (2016), evaluated different concentrations of indole-3-butyric acid (IBA) and three types of substrates in the production of pita tree seedlings and recorded an average of 1.6 sprouts in cuttings with 25 cm in length treated with 1000 mg L^{-1} of IBA planted in the substrate containing only sand. The results obtained in the present work show similarities of means for the substrate S2 - sand + manure (Fig. 2), highlighting that there was no use of IBA or any other phytoregulator. The shoots recorded for the substrate S1 - millicompost exceeded the average of 1.5 shoots, 89.33% higher than the result found by the aforementioned authors.

The length of the cuttings is capable of influencing both the carbohydrate reserves and the volume of endogenous auxins, contributing to greater survival, faster emission of roots, in addition to interfering in the number and size of shoots produced during initial growth (Pontes Filho et al., 2014). Moreira et al. (2017) in order to determine the best cut length for the production of the dragon fruit tree seedlings in a protected environment, recorded the average value of 30 cm in the longest shoot length in cuttings of 30 cm in length. In this work, the length of the largest sprout was 38.16 cm in the substrate S1-millicompost (Fig. 2), being superior to the other substrates by 67% and 445.92%, when compared to the substrates S2 and S3 and 8.16 cm greater than the length recorded by Moreira et al. (2017).

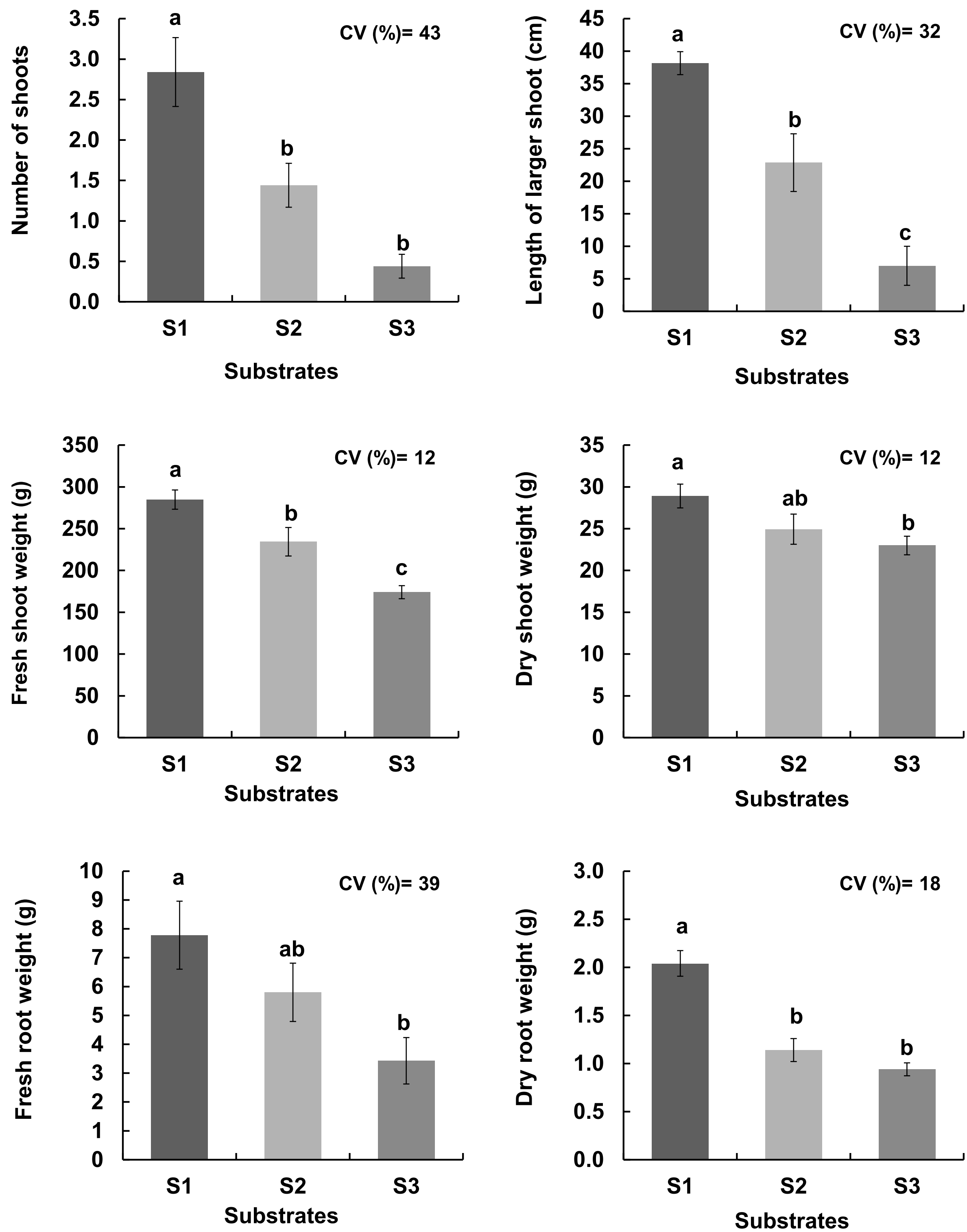

Fig. 2. Number of shoots, length of the largest shoot, fresh and dry weight of the shoots, fresh and dry weight of roots of cuttings of white pulp of red dragon fruit tree with their respective coefficients of variation (CV) and standard error. Equal letters in the bars do not differ by Tukey's test ($p < 0.05$). S1 - millicompost; B) S2 - sand + manure; C) S3 - Biomix®.

Pontes Filho et al. (2014) aiming to evaluate the effect of the application of indolbutyric acid and length of cuttings on the rooting of the dragon fruit tree (5–14 cm and 17–26 cm) found average values of fresh mass of the shoots varying from 19.21 to 71.09 g, while the dry mass of the shoots varied from 1.24 to 3.98 g. In our work, the substrate that presented the lowest phytotechnical performances - S3-Biomix® substrate, whose averages were 173.95 and 22.99 g of the fresh and dry shoot part masses, respectively (Fig. 2), exceed the averages found by the authors mentioned above. The same authors recorded averages for dry root mass ranging from 2.65 to 7.13 g, with plants propagated by large cladodes having the most expressive values regardless of the application of exogenous auxin. In this work, the substrate

Fig. 3. Visual aspect of red dragon fruit tree seedlings of white pulp propagated by cuttings on different substrates after 90 days of cutting. A) S1 - millicompost; B) S2 - sand + manure; C) S3 - Biomix®. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

S3-millicompost showed average values higher than the other substrates (Fig. 2). Probably the lack of application of indolbutyric acid resulted in lower gains for the root masses of all evaluated substrates.

The cuttings of dragon fruit tree respond well to the organic matter, since the organic sources supply the inorganic N gradually, as the mineralization of the organic matter occurs (Nerd and Mizrahi, 1999; Rodrigues and Casali, 1999), which is observed in substrate S1 - millicompost. This performance can also be indirectly related to the hormonal effect that humic substances present in organic substrates exert on plants (Cordeiro et al., 2010), although not quantified in this work.

There is little literature related to substrates originating from the activity of diplopods (millicomposts), however, Thakur et al. (2011) proved that millicompost is superior to vermicompost and common compost, having a positive effect on plant growth. Ramanathan and Alagesan (2012) when using the millicompost, vermicompost and compost in the production of Capsicum annuum, observed that the greatest gains in the number of leaves, leaf area, plant height, number and weight of fruits occurred in the plants developed in the millicompost, attributing these results to its physical and chemical properties of this substrate.

Recently, Antunes et al. (2018) evaluated the agronomic performance of lettuce seedlings produced with millicompost and found that

effectively the millicompost can be used as a substrate, because in addition to providing the formation of higher quality lettuce seedlings, it directly reflects on the performance of the crop, with gains that surpass the productivity averages found in other jobs for the same cultivar.

3.4. Macronutrient content present in the shoot dry mass of cuttings dragon fruit tree

The seedlings produced with the substrates S1 - millicompost and S2 - sand + manure showed higher levels of N, P, K and Mg ($p < 0.05$) accumulated in their aerial parts, except for calcium, whose contents were similar between the seedlings produced on the three different substrates (Fig. 4).

According to Rozane et al. (2011), variations in the accumulation of nutrients can occur when using different cultivation media, thus, it can be observed that the seedlings produced using the millicompost presented higher levels of nitrogen when compared to those of the other substrates, confirming that the aforementioned compost favors the supply of this nutrient so important for development, especially during the vegetative phase, when it is most required by plants. The

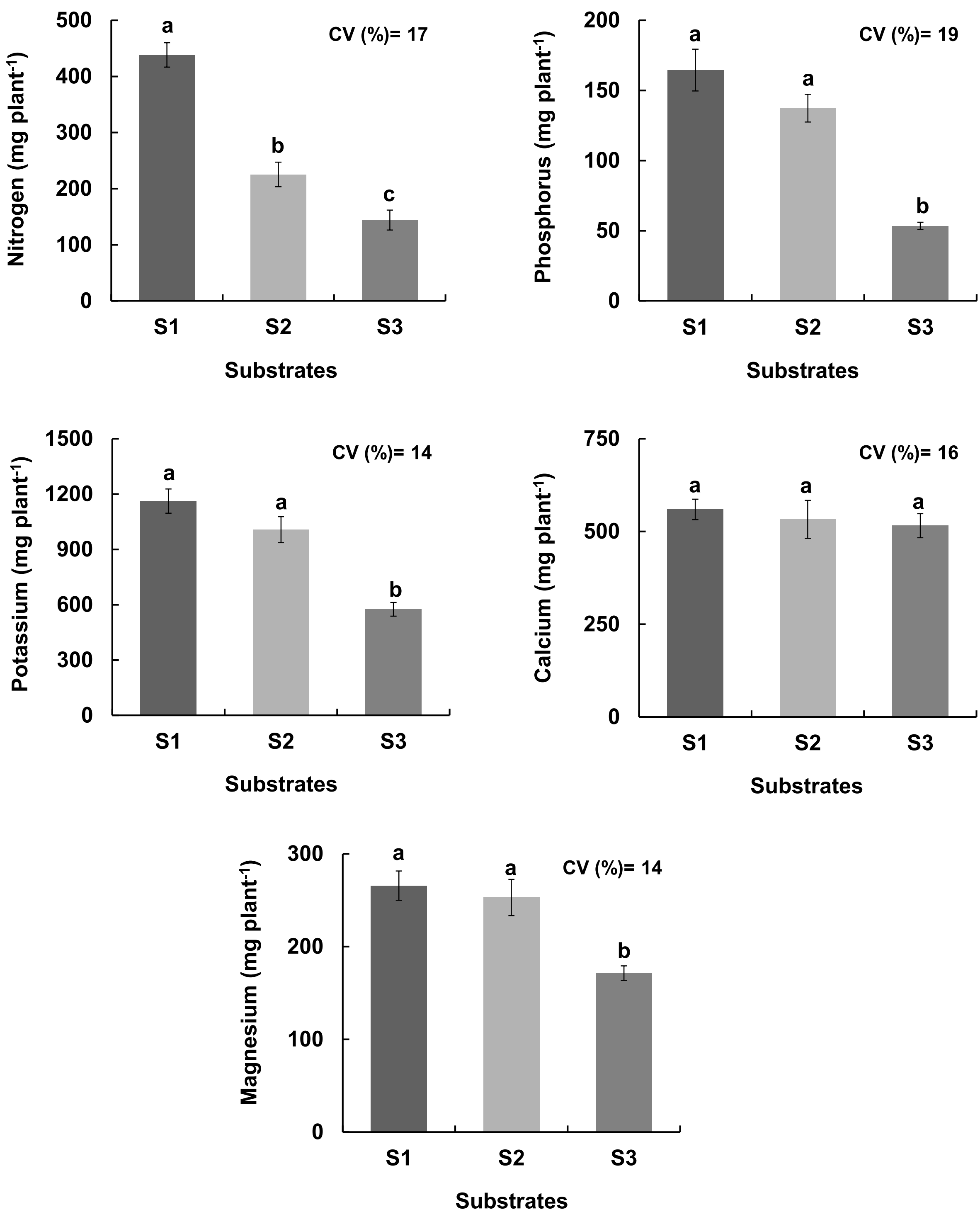

Fig. 4. Content of the macronutrients present in the shoot dry mass of the red dragon fruit tree seedlings propagated by cuttings with their respective coefficients of variation (CV) and standard error. Equal letters in the bars do not differ by Tukey's test ($p < 0.05$). S1 - millicompost; B) S2 - sand + manure; C) S3 - Biomix®.

accumulated values of N in the seedlings from the substrate S1 and S2 represent 206 and 57% more of this nutrient in relation to the substrate S3. Lima et al. (2019), observed, during a period of 60–120 days, the accumulation of 830 mg of N in red dragon fruit trees.

The amount of phosphorus extracted from the seedlings is of great importance, since this element directly influences the initial stage of root development, in addition to its effective participation in the photosynthetic processes which, in the culture in question, becomes even more relevant since the cladode it is a photosynthetically active organ (Moreira et al., 2020). The substrates S1 and S2 promoted accumulations of phosphorus whose percentages were 209 and 158%, respectively, when compared to the commercial substrate - S3 ($p < 0.05$), as can be seen in Fig. 4. Lima et al. (2019) reported an accumulation of 160 mg plant^{-1} of P in a red dragon fruit tree, in an interval of 60–120 days, being similar to the P accumulated in the seedlings originating from the millicompost (S1).

Note in Fig. 4 that the levels of potassium extracted from the seedlings produced with the substrates S1 and S2 were higher than S3, corresponding to 102% and 75% more of this nutrient, respectively. According to Marschner (2012), this nutrient is related to the process of translocation of carbohydrates, in addition to the opening and closing of stomata. Moreira et al. (2017) and Lima et al. (2019) observed that potassium was the element most extracted by the dragon fruit tree in its initial development, whose accumulation found was 940 mg of K in an interval of 60–120 days, corroborating with our results, whose values were close.

The similarity in the calcium accumulation in the dragon fruit tree seedlings developed in the different substrates (Fig. 4) probably occurred due to the fact that this nutrient presents low mobility in the phloem (Malavolta, 2006), which can vary according to the phenology of the plant, being necessary studies with the cuttings in the field to verify possible variations in the amount of Ca extracted and accumulated, since, Lima et al. (2019) observed that this nutrient is the most required between 180 and 240 days after the planting of cuttings of *Selenicereus* sp (red dragon fruit tree), whose accumulation was 440 mg of this nutrient. Moreira et al. (2012) also found no differences in Ca levels in cladodes of *Selenicereus undatus* (Haw.) (Britton & Rose) (red dragon fruit tree) fertilized with different organic sources.

For magnesium, the seedlings produced with the substrates S1 and S2 showed an extraction 55 and 47% higher, respectively, when compared to the seedlings from the commercial substrate (S3) (Fig. 4). Lima et al. (2019) found 270 mg plant^{-1} evaluating the accumulation of nutrients in red dragon fruit tree, within an interval of 60–120 days after planting the cuttings, a value similar to those found in dragon fruit tree seedlings developed on substrates S1 and S2. Among the functions of magnesium, its role in the composition of the chlorophyll molecule stands out, participating in various processes, such as photosynthesis, respiration, synthesis of carbohydrates and proteins (Pereira et al., 2020).

Antunes et al. (2016) found that the millicompost produced from various agricultural and urban residues, processed by the species *Trigoniulus corallinus*, contains amounts of calcium, magnesium and phosphorus favorable to the development of lettuce seedlings. Furthermore, considering that the millicompost used in this work followed the production methodology proposed by the aforementioned authors, its efficiency in the production of pitaya seedlings is confirmed.

In general, the data obtained in this work corroborate Makkar et al. (2017), who claim that the concentration of nutrients in plant tissues has been shown to be directly proportional to the concentration of nutrients contained in the substrates on which they developed.

New studies must be carried out to evaluate the quality of the compost produced from other raw materials, in addition to developing works that accompany the development of this culture in the production fields, given that the millicompost promotes a differentiated growth in relation to the other substrates, which can result in premature production.

Millicompost is an organic substrate of easy production that presents physical and chemical characteristics suitable for plant development during the seedling stage. Furthermore, it is a ready-to-use organic compost that spares the combination with other feedstock, reducing the costs for farmers. The potential of millicompost for enhancing plant growth by producing humic substances and biological properties such as stimulating growth-promoting microorganisms deserve further studies.

Our work shows that millicompost is rich in nutrients. As its production shows a yield between 30 and 40%, future research is suggested to increase its yield as a substrate by combining it with other organic materials, such as: urban pruning, crushed coconut fiber or residues from the agribusiness. Thus, there will be the possibility of obtaining one or more substrates formulated based on millicompost, capable of promoting effects similar to those obtained with millicompost without any combination, combining economy and sustainability in a single product.

Another point to be considered is the biology of millipedes, which, unlike already domesticated earthworms, have lower survival rates in confined environments (since puppy to adulthood phase, which vary according to each species). This is an obstacle and at the same time deserves further studies in order to create strategies that further enhance their reproduction and survival rates. In this way, we will be able to reach the level of transferring the reproduction technology of these animals to the whole society, because in the last three years the millicomposting process has been sought and implemented by rural and urban farmers, besides Agroecology sympathizers throughout the Brazil.

4. Conclusions

The millicompost has an efficiency in the performance of the red dragon fruit tree of white pulp seedlings, providing increments of the vegetative characters and of biomass production, confirmed by the great contributions of nutrients accumulated in its vegetal tissue. This indicates a new and excellent alternative of substrate of organic origin in the vegetative propagation of the species with superior quality than formulated and commercial substrates.

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CRediT authorship contribution statement

Luiz Fernando de Sousa Antunes: Conceptualization, Methodology, Investigation, Formal analysis and data curation, Visualization, Supervision, Writing— original draft preparation and Writing—review and editing. André Felipe de Sousa Vaz: Investigation, Visualization and Writing—review and editing. Maura Santos Reis de Andrade da Silva: Visualization and Writing—review and editing. Maria Elizabeth Fernandes Correia: Resources and Funding acquisition. Fábio Ferreira Cruvinel: Conceptualization, Methodology, Investigation, Visualization, Supervision, Writing— original draft preparation. Luiz Aurélio Peres Martelleto: Investigation, Visualization, Supervision and Writing—review and editing.

Conflict of interest

The authors declare that they have no conflict of interest.

Data availability statements

All data generated or analyzed during this study are included in this published article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Almeida, E.I.B., Corrêa, M.C. de M., Cajazeira, J.P., Queiroz, R.F., Barroso, M.M.A., Marques, V.B., 2016. Cultivo de Hylocereus sp. com enfoque na propagação vegetativa, sombreamento e adubação mineral. Rev. AGROMBIENTE -LINE 10, 65–76. https://doi.org/10.18227/1982-8470ragro.v10i1.2823.

Antunes, L.F.S., Scoriza, R.N., França, E.M., Silva, D.G., Correia, M.E.F., Leal, M.A.A., Rouws, J.R.C., 2018. Desempenho agronômico da alface crespa a partir de mudas produzidas com gongocomposto. Rev. Bras. Agropecuária Sustentável 8, 57–65. https://doi.org/10.21206/rbas.v8i3.3009.

Antunes, L.F.S., Scoriza, R.N., Silva, D.G., Correia, M.E.F., 2019a. Consumo de resíduos agrícolas e urbanos pelo diplópode Trigoniulus corallinus. Nativa 7, 162–168. https://doi.org/10.31413/nativa.v7i2.6192.

Antunes, L.F.S., Scoriza, R.N., Silva, D.G., Correia, M.E.F., 2016. Production and efficiency of organic compost generated by millipede activity. Ciência Rural. 46, 815–819. https://doi.org/10.1590/0103-8478cr20150714.

Antunes, L.F.S., Siva, D.G., Correia, M.E.F., Leal, M.A.A., 2019b. Avaliação química de substratos orgânicos armazenados e sua eficiência na produção de mudas de alface. Rev. Científica Rural 21, 139–155. https://doi.org/10.30945/rcr-v21i2.2680.

Apurva, P., Thakur, P.C., Sinha, S.K., 2014. Caracteristics of organic compost originated from Harpaphe haydeniana (Wood) and Eisenia foetida. Int. J. Exch. Knowl. 1, 4.

Ashwini, K.M., Sridhar, K.R., 2006. Breakdown of plantation residues by pill millipedes (Arthrosphaera magna) and assessment of compost quality. Curr. Sci. 90, 954–959.

Brasil, 2008. Ministério da Agricultura, Pecuária e abastecimento (MAPA). Secretaria de Defesa Agropecuária (SDA). Instrução Normativa SDA Nº 31 de 23 de outubro de 2008. Altera os subitens 3.1.2, 4.1 e 4.1.2, do Anexo da Instrução Normativa SDA nº 17, de 21 de maio 2007. Métodos Analíticos Oficiais para Análise de Substratos para Plantas e Condicionadores de Solo. Diário Oficial da União, Brasília, DF, 24 de dez.

Brasil, da Agricultura, Ministério, de Abastecimento, Pecuária, (Mapa), 2009. Instrução Normativa Nº 25, de 23 de julho de 2009. Aprova as Normas sobre as especificações e as garantias, as tolerâncias, o registro, a embalagem e a rotulagem dos fertilizantes orgânicos simples, mistos, compostos, organominerais e biofertilizantes destinados à agricultura. Diário Oficial da União, Brasília, DF, pp. 20–23. Seção 1, jul.

Bugni, N.O.C., Antunes, L.F.S., Guerra, J.G.M., Correia, M.E.F., 2019. Gongocomposto: substrato orgânico proveniente de resíduos de poda para produção de mudas de alface. Rev. Bras. Agropecuária Sustentável 9, 68–77. https://doi.org/10.21206/rbas.v9i3.8107.

Cordeiro, F., Fernandes, M.S., Souza, S., 2010. Influência dos ácidos húmicos no metabolismo vegetal pode ser considerada uma resposta auxínica? Rev. Ciênc. Vida 30, 11–131.

Da Ros, C.O., Rex, F.E., Ribeiro, I.R., Kafer, P.S., Rodrigues, A.C., Silva, R.F., Somavilla, L., 2015. Uso de Substrato Compostado na Produção de Mudas de Eucalyptus dunnii e Cordia trichotoma. Floresta E Ambiente 22, 549–558. https://doi.org/10.1590/2179-8087.115714.

Donadio, L.C., 2009. Pitaia. Rev. Bras. Frutic. 31, 637–929.

Fermino, M.H., 2003. Métodos de análise para caracterização física de substratos para plantas. Universidade Federal do Rio Grande do Sul, Porto Alegre-RS.

Ferreira, D.F., 2014. Sisvar: a Guide for its Bootstrap procedures in multiple comparisons. Cienc. E Agrotecnol 38, 109–112. https://doi.org/10.1590/S1413-70542014000200001.

Filho, F.S.T.P., Almeida, E.I.B., Barroso, M.M.A., Cajazeira, J.P., Corrêa, M.C. de M., 2014. Comprimento de estacas e concentrações de ácido indolbutírico (AIB) na propagação vegetativa de pitaia. Rev. Cienc. Agron. 45, 788–793.

Galvão, E.C., Ramos, J.D., Pio, L.A.S., Laredo, R.R., Silva, F.O.R., Miranda, J.M.S., 2016. Substratos e ácido indol-3-butírico na produção de mudas de pitaia vermelha de polpa branca. Rev. Ceres 63, 860–867. https://doi.org/10.1590/0034-737x201663060016.

Goldin, A., 1987. Reassessing the use of loss-on-ignition for estimating organic matter content in noncalcareous soils. Commun. Soil Sci. Plant Anal. 18, 1111–1116. https://doi.org/10.1080/00103628709367886.

Gonçalves, J.L.M., Poggiani, F., 1996. Substrato para produção de mudas florestais. In: Resumos Expandidos. Presented at the Solo-Suelo- Congresso Latino Americano de Ciência do Solo, Águas de Lindóia: SLCS/SBCS.

Gonçalves, M.J., Camargo, S.S., Arruda, A.L., Rufato, L., 2020. Rápida produção de mudas de pitaia (Hylocereus undatus, Cactaceae) por meio da técnica da micropropagação. Acta Biológica Catarin. 7, 75–81. https://doi.org/10.21726/abc.v7i1.632.

Jiménez, E.I., García, V.P., 1992. Relationships between organic carbon and total organic matter in municipal solid wastes and city refuse composts. Bioresour. Technol. 41, 265–272. https://doi.org/10.1016/0960-8524(92)90012-M.

Kämpf, A.N., 2011. Análise física de substratos para plantas (No. 26), Boletim informativo. Sociedade Brasileira de Ciência do Solo (SBCS) (Viçosa-MG).

Kratz, D., Wendling, I., Nogueira, A.C.N., Souza, P.V.D.S., 2013. Propriedades físicas e químicas de substratos renováveis. Rev. Árvore 37, 1103–1113. https://doi.org/10.1590/S0100-67622013000600012.

Lima, D. de C., Mendes, N.V.B., Corrêa, M.C.M., Taniguchi, C.A.K., Queiroz, R.F., Natale, W., 2019. Crescimento e acúmulo de nutrientes na parte aérea da Pitaia Vermelha (Hylocereus sp.). Rev. Bras. Frutic. 41, 1–11. https://doi.org/10.1590/0100-29452019030.

Makkar, C., Singh, J., Parkash, C., 2017. Vermicompost and vermiwash as supplement to improve seedling, plant growth and yield in Linum usitassimum L. for organic agriculture. Int. J. Recycl. Org. Waste Agric. 6, 203–218. https://doi.org/10.1007/s40093-017-0168-4.

Malavolta, E., 2006. Manual de nutrição mineral de plantas (CERES, São Paulo-SP).

Marschner, H., 2012. Nutrição mineral de plantas superiores, third ed. Academic Press, Londres.

Minami, K., Salvador, E.D., 2010. Substrato para plantas. Degaspari, Piracicaba-SP.

Mizrahi, Y., 2014. Vine-cacti pitayas: the new crops of the world. Rev. Bras. Frutic. 36, 124–138. https://doi.org/10.1590/0100-2945-452/13.

Moreira, A.R., Souza, F.L.B., Silva, R.T.L., Oliveira, R.L.L., Alonço, A.S., Neto, C.F.O., Souza, S.K.A., 2017. Determinação do comprimento da estaca para a produção de mudas de pitaia (Hylocereus costaricensis) em ambiente protegido. Tecno-Lóg. 21, 41–45. https://doi.org/10.17058/tecnolog.v21i2.8734.

Moreira, R.A., Cruz, M.C.M. da, Fernades, D.R., Oliveira, J., 2020. Adubação fosfatada no crescimento e nos teores de nutrientes em cladódios de pitaia vermelha. Agrarian 13, 377–384. https://doi.org/10.30612/agrarian.v13i49.9148.

Moreira, R.A., Ramos, J.D., Araújo, N.A., Marques, V.B., Melo, P.C., 2012. Produtividade e teores de nutrientes em cladódios de pitaia vermelha utilizando-se adubação orgânica e granulado bioclástico. Rev. Bras. Ciênc. Agrár. - Braz. J. Agric. Sci. 7, 714–719. https://doi.org/10.5039/agraria.v7isa1551.

Nunes, E.N., Sousa, A.S.B., Lucena, C.M., Silva, S.M., Lucena, R.F.P., Alves, C.A.B., Alves, R.E., 2014. Pitaia (Hylocereus sp.): Uma revisão para o Brasil. Gaia Sci 8, 90–98.

Oliveira Júnior, J.F., Delgado, R.C., Gois, G., Lannes, A., Dias, F.O., Souza, J.C., Souza, M., 2014. Análise da precipitação e sua relação com sistemas meteorológicos em Seropédica, Rio de Janeiro. Floresta E Ambiente 21, 140–149. https://doi.org/10.4322/floram.2014.030.

Pascual, J.A., Ceglie, F., Tuzel, Y., Koller, M., Koren, A., Hitchings, R., Tittarelli, F., 2018. Organic substrate for transplant production in organic nurseries. A review. Agron. Sustain. Dev. 38, 35. https://doi.org/10.1007/s13593-018-0508-4.

Pereira, C.M.S., Antunes, L.F.S., Aquino, A.M., Leal, M.A.A., 2020. Substrato à base de esterco de coelho na produção de mudas de alface. Nativa 8, 58–65. https://doi.org/10.31413/nativa.v8i1.8018.

Ramanathan, B., Alagesan, P., 2012. Evaluation of millicompost versus vermicompost. Curr. Sci. 103, 140–143.

Rozane, D.E., Prado, R.M., Natale, W., Franco, C.F., 2011. Crescimento, teor e acúmulo de nutrientes em hipobiotos de caramboleiras, cultivados em diferentes soluções nutritiva. Rev. Ceres 58, 366–372. https://doi.org/10.1590/S0034-737X2011000300018.

Teixeira, P.C., Donagema, G.K., Fontana, A., Teixeira, W.G., 2017. Manual de métodos de análise de solo, third ed. Embrapa, Brasília-DF.

Thakur, P.C., Apurva, P., Sinha, S.K., 2011. Comparative study of characteristics of biocompost produced by millipedes and earthworms. Adv. Appl. Sci. Res. 2, 94–98.